

NMR (CDCl₃) δ 5.65, 96.84, 127.33, 128.05, 129.01, 134.29, 189.49. Anal. Calcd for C₁₆H₁₄Cl₂NS₂: C, 49.18; H, 3.62; Cl, 27.20; N, 3.58; S, 16.41. Found: C, 49.35; H, 3.64; Cl, 26.93; N, 3.52; S, 16.44.

Dichloro(1,1,1-trichloromethyl)thio]methanesulfonyl Chloride (10). A solution of 1.1 g (15 mmol) of Cl₂ in 25 mL of CCl₄ was added to 3.5 g (15 mmol) of 2 in 25 mL of CCl₄ at 0 °C. The reaction mixture was allowed to warm to room temperature and after 5 h the solvent was removed in vacuo. The remaining yellow oil was distilled in vacuo, giving 2.7 g (60%) of a yellow oil (bp 134–137 °C (11 torr)), which could be identified as 10: MS, *m/z* 298 (M⁺), 263 (M⁺ - Cl), 228 (M⁺ - Cl₂), 193 (M⁺ - 3Cl), 184 (M⁺ - Cl₂CS), 149 (Cl₂CS⁺), 117 (CCl₃⁺), 79 (CSCl⁺), 76 (CS₂⁺); IR (NaCl, cm⁻¹) 830 (vs), 770 (vs), 745 (vs); ¹³C NMR (C₆D₆) δ 95.63, 95.72. Anal. Calcd for C₂Cl₆S₂: C, 7.99; Cl, 70.70; S, 21.31. Found: C, 8.56; Cl, 70.83; S, 21.50.

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Registry No. 1, 594-42-3; 2, 91631-89-9; 6, 91631-90-2; 8, 91631-91-3; 9, 91631-92-4; 10, 91631-93-5; (PhCH₂)₂NH, 103-49-1; Cl₂, 7782-50-5; CS₂, 2944-05-0; anthracene, 120-12-7.

Synthetic Methods and Reactions. 119.¹
N-Formylmorpholine: A New and Effective
Formylating Agent for the Preparation of
Aldehydes and Dialkyl
(1-Formylalkyl)phosphonates from Grignard or
Organolithium Reagents

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In recent years a number of reagents have been developed for formylation in organic synthesis. 2-(Formylmethylamino)pyridine has been used by Comins and Meyers² for the preparation of aldehydes from Grignard reagents. The presence of the additional ligand (pyridyl nitrogen) and the ready formation of a six-membered chelate ring was considered to prohibit release of aldehyde under the reaction conditions and thus protect the aldehydic product from the further reaction with the organometallic reagent. We subsequently reported³ the use of *N*-formylpiperidine in related reactions and found that no additional ligand is in fact necessary for the reaction to be successful. More recently, Amaratunga and Frechet reported⁴ a more extensive investigation of the formylation of Grignard reagents with alkylformylamines. The ready availability of dialkylformamides such as DMF makes them also increasingly useful in the preparation of aldehydes.⁵ The reactions, however, have limitations and generally proceed satisfactorily with Grignard but not with organolithium reagents. Aboujaoude and Collignon re-

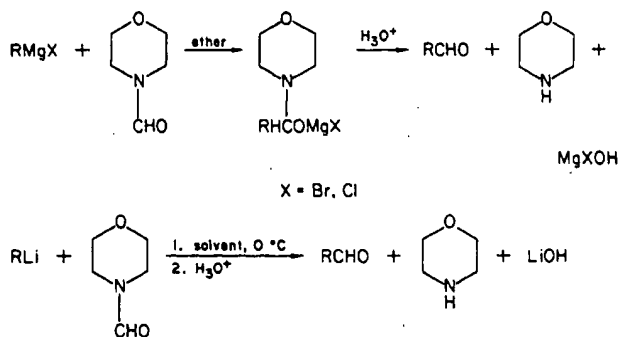
Table I. Aldehydes by Reaction of Grignard and Organolithium Reagents with *N*-Formylmorpholine

RMgX or RLi	yield, %	solvent	bp [°C/mmHg]	
			found	lit. ³
C ₆ H ₅ CH ₂ CH ₂ -MgCl	70	ether	88/1	87/1
C ₆ H ₅ CH=CH-MgBr	81	ether	84/2	85/2
C ₆ H ₅ CH ₂ MgCl	84	ether	76-79/10	76-78/10
norbornyl-MgBr	74 ^b	ether	51-53/7	52/7
c-C ₆ H ₅ MgBr	69	ether	74-75/100	73-76/100
1-naphthyl-MgBr	92	ether	142/6	142/6
C ₆ H ₅ MgBr	89	ether	51-52/2.2	63-64/10
C ₆ H ₅ Li	90	benzene	50/2.2	63-64/10
<i>n</i> -BuLi	78	<i>n</i> -hexane	100/760	102-103/760
C ₆ H ₅ C≡CLi	80	ether	65/0.1	65/0.1

^a Yields of aldehydes refer to isolated (distilled) products; they gave IR, ¹H NMR, and ¹³C NMR spectra which were identical with those of the authentic compounds. ^b Starting with pure *exo*-norbornyl bromide produces a mixture of *exo*- and *endo*-norbornene carboxaldehyde (3:1), which was characterized by NMR spectroscopy.

ported⁶ the preparation of dialkyl (1-formylalkyl)-phosphonates, via treatment of dimethylformamide with the dialkyl (α -lithioalkyl)phosphonates. The isolated yields were from 52% to 88%.

Our continued interest in developing alternative and improved formylating systems prompted us to examine the readily available and inexpensive *N*-formylmorpholine as a formylating reagent. The reagent is commercially available or easily prepared by the reaction of morpholine with carbon monoxide. *N*-Formylmorpholine readily reacts with organometallic compounds. Reaction in ether at 0 °C with wide variety of organolithium or Grignard reagents results in formation, upon acidic workup, of the corresponding aldehydes (Table I) in good to excellent yield and high purity. The examples in Table I indicate the effectiveness of the method for aryl, alkyl, vinyl, and acetylenic Grignard or organolithium reagents alike.



The reaction of dialkyl (α -lithioalkyl)phosphonates with *N*-formylmorpholine in THF at -78 °C upon acidic workup also gives in excellent yield dialkyl (1-formylalkyl)-phosphonates, affording a method of wide applicability for their one-step preparation from the parent phosphonates (Table II).⁷

The ease of the reactions and mild conditions, giving excellent preparative yields, make this formylating reagent

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(2) Comins, D. L.; Meyers, A. I. *Synthesis* 1978, 403 and references cited therein. Meyers, A. I.; Comins, D. L. *Tetrahedron Lett.* 1978, 5179.

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(7) Ford-Moore, A. H.; Perry, B. J. "Organic Syntheses"; Wiley: New York, 1963; Collect. Vol. IV, p 325.

Table II. Preparation of Dialkyl (1-Formylalkyl)phosphonates 5

R ₁	R ₂	R ₃	yield		bp [°C/mmHg]	
			present run	reported ^a	found	lit. ^a
C ₂ H ₅	H	H	85	53	72-76/0.25	76-79/0.3
<i>i</i> -C ₃ H ₇	H	H	83	51	72-78/0.5	94-98/2
C ₂ H ₅	CH ₃	H	94	86	93-5/2	93-96/2
<i>i</i> -C ₃ H ₇	CH ₃	H	91	88	80-85/1	98-102/2
C ₂ H ₅	CH ₃	CH ₃	83	79	98-100/4	88-91/2
C ₂ H ₅	C ₂ H ₅	H	80	78	98-102/2.8	96-99/2

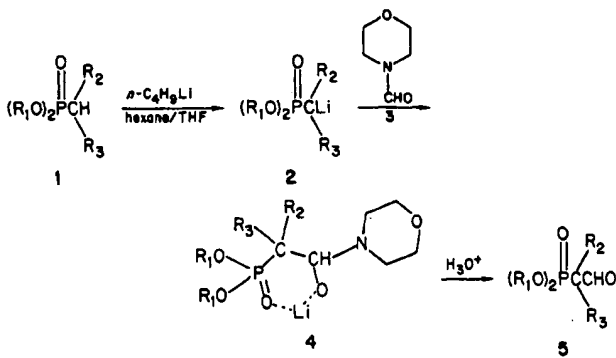
^a Yields of dialkyl (1-formylalkyl)phosphonates refer to isolated (distilled) products; they gave ¹H NMR and ³¹P NMR spectra which were identical with those of the reported^a compounds.

an attractive one complementing previously reported methods.

Further purification by distillation furnished pure products which were characterized by their bp, IR, ¹³C NMR, ¹H NMR, and TLC.

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Registry No. 1 (R₁ = C₂H₅, R₂ = R₃ = H), 683-08-9; 1 (R₁ = *i*-C₃H₇, R₂ = R₃ = H), 1445-75-6; 1 (R₁ = C₂H₅, R₂ = CH₃, R₃ = H), 78-38-6; 1 (R₁ = *i*-C₃H₇, R₂ = CH₃, R₃ = H), 1067-69-2; 1 (R₁ = C₂H₅, R₂ = R₃ = CH₃), 1538-69-8; 1 (R₁ = R₂ = C₂H₅, R₃ = H), 18812-51-6; 2 (R₁ = C₂H₅, R₂ = R₃ = H), 41849-03-0; 2 (R₁ = *i*-C₃H₇, R₂ = R₃ = H), 91210-94-5; 2 (R₁ = C₂H₅, R₂ = CH₃, R₃ = H), 91210-95-6; 2 (R₁ = *i*-C₃H₇, R₂ = CH₃, R₃ = H), 91210-96-7; 2 (R₁ = C₂H₅, R₂ = R₃ = CH₃), 91210-97-8; 2 (R₁ = R₂ = C₂H₅, R₃ = H), 91210-98-9; 3, 4394-85-8; 5 (R₁ = C₂H₅, R₂ = R₃ = H), 1606-75-3; 5 (R₁ = *i*-C₃H₇, R₂ = R₃ = H), 43186-09-0; 5 (R₁ = C₂H₅, R₂ = CH₃, R₃ = H), 34403-79-7; 5 (R₁ = *i*-C₃H₇, R₂ = CH₃, R₃ = H), 67398-17-8; 5 (R₁ = C₂H₅, R₂ = R₃ = CH₃), 35078-65-0; 5 (R₁ = R₂ = C₂H₅, R₃ = H), 32329-34-3; C₆H₅CH₂CH₂MgCl, 90878-19-6; C₆H₅CH=CHMgBr, 30094-01-0; C₆H₅CH₂MgCl, 6921-34-2; *c*-C₆H₅MgBr, 33240-34-5; C₆H₅MgBr, 100-58-3; C₆H₅Li, 591-51-5; C₆H₅C≡CLi, 4440-01-1; C₆H₅CH₂CH₂CHO, 104-53-0; C₆H₅C≡CH=CHCHO, 104-55-2; C₆H₅CH₂CHO, 122-78-1; *c*-C₆H₅CHO, 872-53-7; C₆H₅CHO, 100-52-7; C₆H₅C≡CCHO, 2579-22-8; *n*-butyllithium, 109-72-8; norbornyl-MgBr, 51243-73-3; 1-naphthyl-MgBr, 703-55-9; norbornyl-CHO, 19396-83-9; 1-naphthyl-CHO, 66-77-3; *n*-butyl-CHO, 110-62-3; lithium, 7439-93-2.



Experimental Section

A. General Procedure for the Formylation of Grignard Reagents with *N*-Formylmorpholine. To a stirred solution of freshly prepared Grignard reagent (10 mmol) in dry diethyl ether (20 mL), cooled to 0 °C, is slowly added during 2 min a solution of *N*-formylmorpholine (Aldrich) (10 mmol) in diethyl ether (10 mL). An exothermic reaction takes place. The reaction mixture is stirred for another 30 min at room temperature and then quenched with 3 N HCl until the solution becomes completely acidic (pH2). The product is extracted with diethyl ether, washed twice with water, and then with saturated sodium hydrogen carbonate and saturated sodium chloride solutions. The organic layers are combined and dried over anhydrous sodium sulfate. Removal of the solvent gives the corresponding aldehyde in almost pure form.⁸ Further purification by either distillation or crystallization furnished pure products which were characterized by their bp, IR, NMR, and TLC.

B. General Procedure for the Formylation of Organolithium Compounds with *N*-Formylmorpholine. To a 0 °C solution of freshly prepared organolithium compound (10 mmol) in the appropriate solvent (see Table I) is added during 2 min a solution of *N*-formylmorpholine (10 mmol) in the same solvent (15 mL). The reaction is moderately exothermic. The solution is allowed to stir for an additional 30 min and then worked up following the procedure described above.⁸

C. General Procedure for the Formylation of Dialkyl Alkylphosphonates with *N*-Formylmorpholine. To a solution of 12 mmol (2.7 M) of *n*-butyllithium in tetrahydrofuran under N₂ at -78 °C is added during 2 min a solution of the dialkyl alkylphosphonate (10 mmol) in 10 mL of tetrahydrofuran. After stirring for 10 min, a solution of *N*-formylmorpholine (12 mmol) in 10 mL of THF is added. The mixture was allowed to warm to room temperature and then is quenched with 3 N HCl until the solution becomes acidic. The product is extracted with dichloromethane, dried over magnesium sulfate, and stripped of solvent to give the corresponding aldehydes in almost pure form.

(8) Spectroscopic evidence showed that the alcohol side product was detectable in some cases (≤5%) but could be easily removed in the purification of the crude product.

Kinetic and Thermodynamic Control in the Metalation of Pyridine. A Direct Synthesis of 2- and 4-Substituted Pyridines

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We recently¹ succeeded in directly metalating pyridine with the complex of BuLi and *t*-BuOK² in a mixture of tetrahydrofuran (THF) and hexane.

The results of quenching the obtained solution with deuteriomethanol, dimethyl disulfide and trimethylchlorosilane indicated that the metalation had afforded a mixture of approximately equal amounts of 2- and 4-potassio derivatives of pyridine in addition to a minor quantity of the 3-potassio compound (~10 rel %). The ratio 2-: 3-: 4-potassio pyridine was completely different from the ratio of the rates with which the 2-, 3-, and 4-

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